
Y-12 Sprinkler Evaluation Tool (SET)

**Nuclear Criticality Safety
and
Fire Protection Engineering
Working as a Team**



Problem

- Lack of consistent guidance on which sprinkler density range should be used in NCS analyses
- Ranges and methodology used historically by NCS analysts are not reviewed by Fire Protection Engineering (FPE)
- No verification that NCS maximum values are calculated correctly or that they bound existing Y-12 nuclear facility sprinkler systems
- Too costly to review every sprinkler system and sprinkler head in every nuclear facility
- Y-12 NCS cannot document subcriticality for all fissile systems for sprinkler densities from 0 g/cc to 1.0 g/cc water

Sprinkler Evaluation Tool (SET)

- Working with FPE, NCS hired a Fire Protection Analyst with extensive Y-12 experience to create a document/method to determine a reasonably bounding volumetric sprinkler density value for standard sprinkler heads in each existing nuclear facility
- Simplifying assumptions:
 - Water pressure for a facility taken at lowest gage where water enters facility determined from highest supply point
 - No credit taken for friction
 - Small (0.02 cm) droplet size used bounds 98% of water volume
 - Assumes all water at 0.02 cm droplet size which maximizes suspension time
 - Average sprinkler discharge used across entire coverage area
 - 24-foot diameter coverage per head used to maximize overlap
- Assumptions were concurred with by NCS and FPE

SET cont'd

- Limitations-areas where FPE must be consulted before SET use:
 - Ceiling heights of <12 feet – 12' used to develop spray pattern
 - Sidewall heads present – potential to impact spray patterns
 - Baffle plates used and sprinkler head spacing closer than 6 feet
 - Spray nozzles instead of or in addition to standard sprinklers
 - Water sheeting/films must be addressed by NCS separately
- SET Capabilities:
 - Ability to calculate per each nuclear facility
 - Ability to calculated based on 6, 7, 8, 9, & 10 foot spacing
 - Ability to consider obstruction head coverage – doubles number of heads used in calculation
 - Ability to add fire department boost (250 psig)
- Worst case maximum sprinkler density for existing Y-12 nuclear facilities was determined to be 0.0034 g/cc
- All Y-12 NCS sprinkler density ranges used are conservative
- Additional SET versions will be developed for HEUMF and UPF facilities

SET Input/Output Screen

Y/DD-1268

SET (Sprinkler Evaluation Tool)

Enter the Building Number

9212

Enter the spacing of the sprinkler heads =

10' X 10'

Are there multiple layers of sprinkler heads?

Yes

Enter the K-Factor of the sprinkler head =

5.8

(5.8 unless otherwise documented)

Fire Department Connection being used?

No

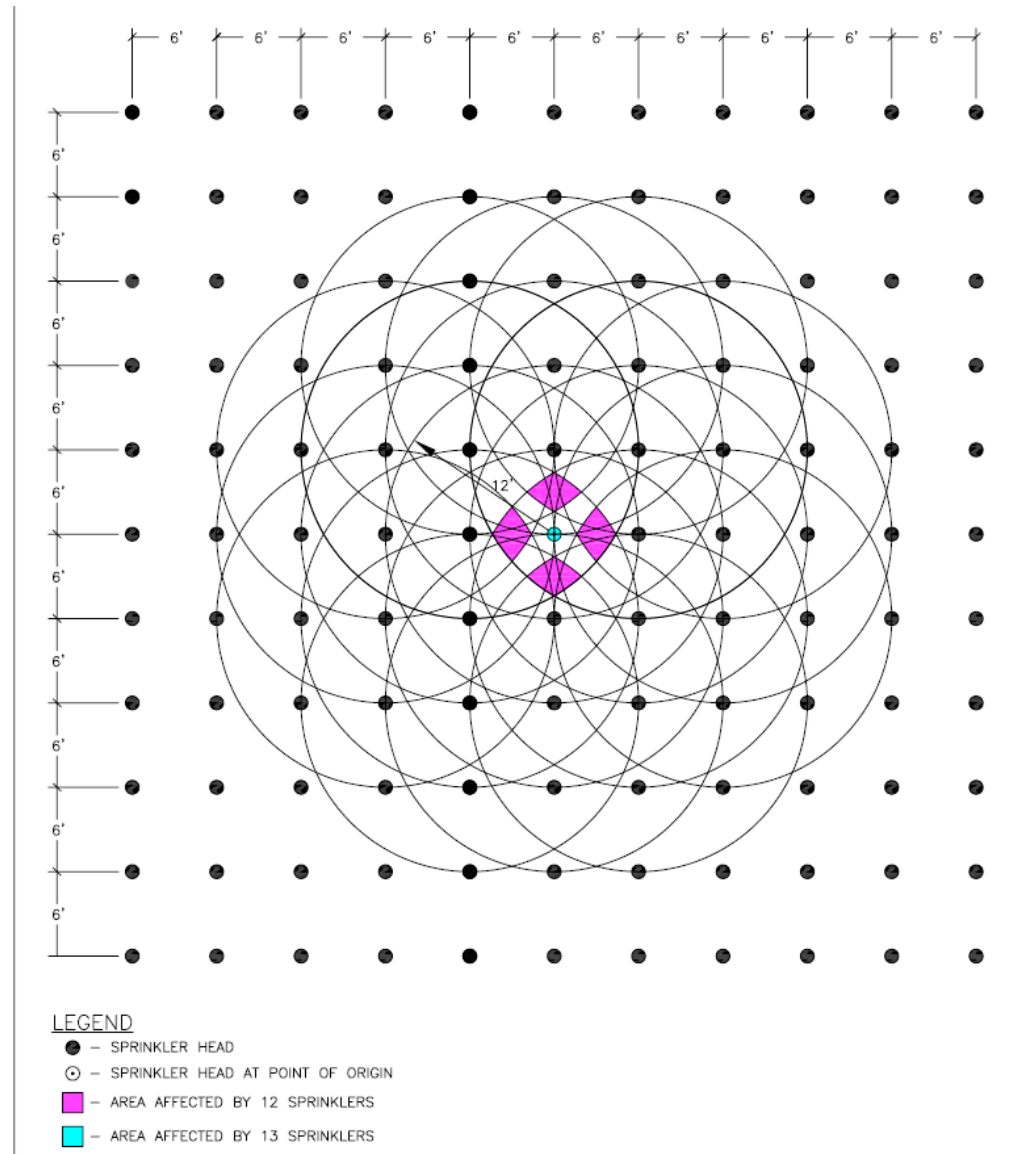
MAXIMUM VOLUMETRIC WATER DENSITY

=

0.0008 | g/cm³

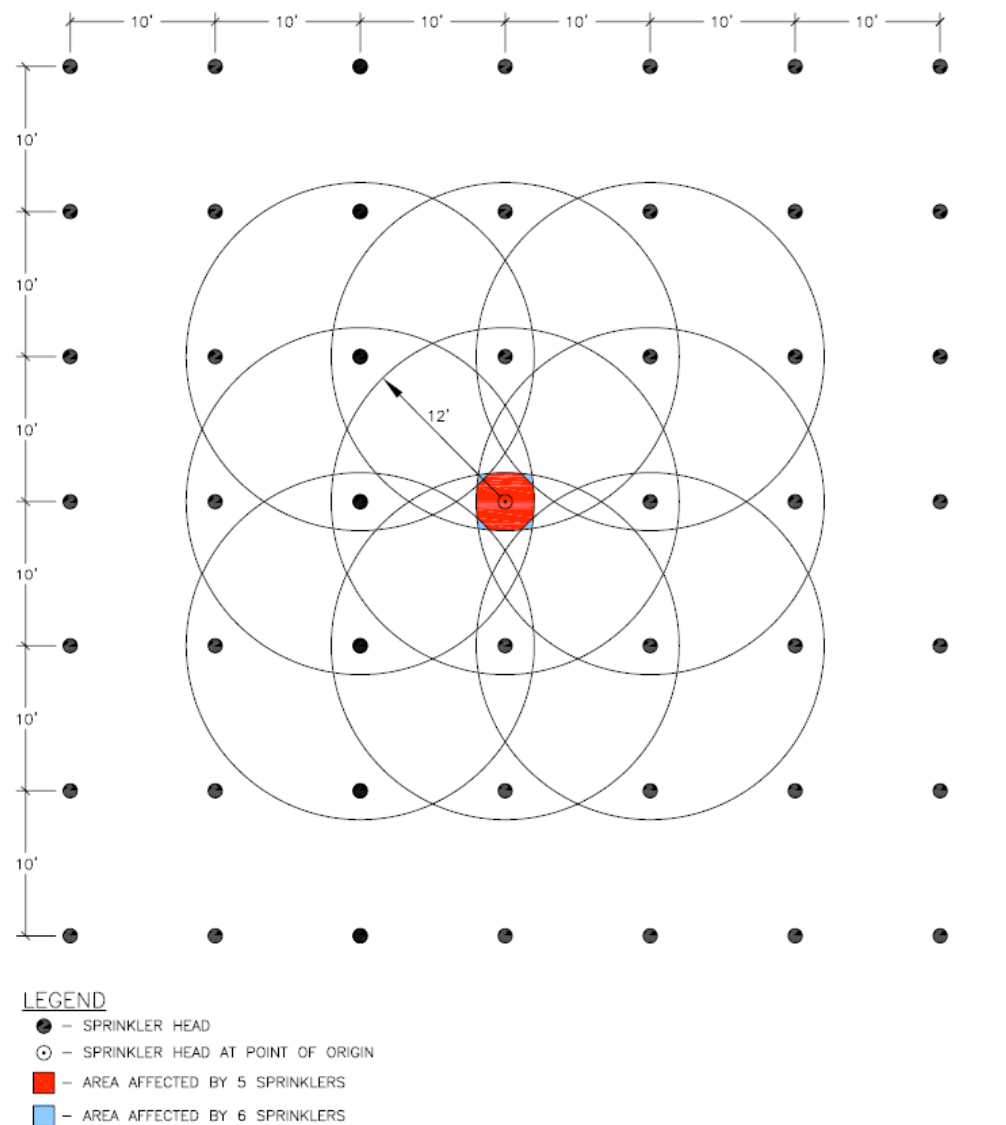
6' x 6' SPRINKLER SPACING

13 MAXIMUM NUMBER OF OPERATING HEADS



10' x 10' SPRINKLER SPACING

6 MAXIMUM NUMBER OF OPERATING HEADS



SET Calculations

Overflow elevation of the water tanks =

1189 ft.

Building for calculation =

9212

Conservative elevation of sprinkler gauge =

1003.58 ft.

Conservative elevation of sprinkler gauge =

0 ft.

Elevation difference (head pressure) =

1003.58 ft.

185.42 ft.

Pressure at system supply gauge (Head X 0.433)

80.3 psig

Is Fire Department Connection Used?

No

0.0 psig

SET Calculations cont'd

Quantity of water being discharged - $Q = K(P)^{1/2}$

Fire Protection Hydraulics and Water Supply Analysis, 2nd Edition,

Brock, Pat, Page 241, Equation 13.8

Operating Pressure of the sprinkler system

P =

80.3 psig

K-Factor for the sprinkler head being used

=

5.8

Quantity of water being discharged - $Q = K(P)^{1/2}$

Q =

51.97 gpm

Area of coverage = $1/4 \cdot \pi \cdot D^2$

Area of the circle is $\pi \cdot R^2$ or $1/4 \cdot \pi \cdot D^2$

Diameter of sprinkler pattern is determined to be 24'

D =

24 ft

Area of sprinkler head coverage is:

A =

452.39 sq ft

SET Calculations cont'd

Volume of water per sq ft per min = Q/A

Quantity of water being discharged	=	51.97	gpm
Area of sprinkler discharge	=	452.39	sq ft
Volume of Water per sq ft per min (FLUX)	=	0.11	gpm/sq ft

Water droplet size = $d_m = (0.86)(30/P_o)^{1/3}$

FMRC, Technical Report J.I. OCG 1E7.RA (1983)

This Section of the Worksheet is being held as a place keeper and is not currently being used in the calculation of the water density per volume. If needed, this section can be activated with the approval of the NCS Manager.

Mean droplet size (mm) for the operating pressure	=		
Operating pressure of the sprinkler system	=	80.3	psig
Mean droplet size in mm is	=	0.62	mm
Convert mm to centimeters X 0.1	=	0.0619	cm

SET Calculations cont'd

Velocity of the droplet size - $\text{Sqrt}(4/3 \cdot 1/4 \cdot 980 \text{ cm/sec}^2 \cdot 0.02 \cdot 1 \text{ g/cm}^3 / 0.00129 \text{ g/cm}^3)$

CSE-PX-069, Rev 4 (Bird, Stewart, and Lightfoot)

This equation is a combination of the equation for drag force and the gravitational force on the droplet.

Solving for V yields the equation above assuming that the drag coefficient is 4

A drag coefficient of 4 was used in the equation based on the calculation of a Reynolds

number of 10.2. Transport Phenomena equates 10.2 to a drag coefficient of 4

Velocity for a droplet size of 0.02 cm =

123.26 cm/s

Volumetric Water Density (g/cm³) - Density =

$(\text{GPM/Sq ft} \cdot 3.785 \text{ liters/gal} \cdot 1000 \text{ g/liter} \cdot 1/930 \text{ cm}^2/\text{ft}^2 \cdot 1/60 \text{ min/sec} \cdot 1 \text{ s/velocity})$

CSE-PX-069, Rev 4 (Bird, Stewart, and Lightfoot)

Volumetric water density is obtained by dividing the flux by terminal velocity

Equation is on Page 42

SET Calculations cont'd

Water density of water per area per min (gpm/sq ft) = 0.11 gpm/sq ft

Volumetric water density per sprinkler head (g/cm³) = 0.000063 g/cm³

Maximum volumetric water density for maximum number of sprinkler heads (g/cm³)

Sprinkler spacing = 10' X 10' Operating Heads = 6

Multiple layers of sprinklers = Yes 2

Total water density per cm³ = 0.000759 g/cm³

Input data is highlighted with

Yellow

Transferred data is highlighted with

Purple

Calculated data is highlighted with

Green

Maximum volumetric density is highlighted in

Brown

Thin Films

- Several calculation approaches were attempted to determine a bounding increase in density to account for thin films.
 - Reactivity variability in 3d model resulted in no reasonably bounding value
- A Literature search found 3 sets of data:
 - Dean, Factory Mutual Research Corp. - source
 - Holmes – 0.55 mm
 - Bidinger – 0.055 cm
 - Ross – Horizontal (2.86-3.58 mm) & Vertical(1.2-3.15 mm) Difference is due to “...conservatively encompasses the embedded stream heights”
 - Source report, *Final Report-Comparison of Gel and Water as Suppressors of Radiant Ignition on Vertical Surfaces* by R.K. Dean, 1972 - is unavailable

Conclusions

- No direct use at other sites – due to Y-12 specific values
- Methodology is applicable to other sites
- Documents that NCS community is typically conservative
- Supports use of more realistic values
- New facility designs may have sprinklers with significantly higher (5.6 - 25.2) K-Factors equates to ~ 0.0135 g/cc water density in air

References

- *Standard for Service Tests of Fire Pump Systems on Fire Apparatus*, NFPA 1911, Natl. Fire Protection Association, Quincy, Mass., 2002.
- A. E. Cote, *Fire Protection Handbook*, 18th ed., Natl. Fire Protection Association, Quincy, Mass., 1997.
- *Automatic Sprinklers for Fire-Protection Service*, Underwriters' Laboratory Standard 199, Underwriters' Lab., Northbrook, Ill., Nov. 4, 2005.
- A. D. Putorti, Jr., T. D. Belsinger, and W. H. Twilley, *Report of Test FR 4003: Determination of Water Spray Drop Size and Speed from a Standard Orifice, Pendent Spray Sprinkler*, Natl. Institute of Standards and Technology, Gaithersburg, Md., May 27, 1999.
- *Standard for the Installation of Sprinkler Systems*, NFPA 13, Natl. Fire Protection Association, Quincy, Mass, 2006.
- *Technical Data Book*, Tyco Fire and Building Products, Lansdale, Pa., 2005, p. 12.
- R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena*, 2nd ed., Wiley, New York, 2002.
- P. D. Brock, *Fire Protection Hydraulics and Water Supply Analysis*, 2nd ed., Fire Protection Publications, Oklahoma State Univ., Stillwater, Okla., 2000.
- H.H. Bidinger, D.A. McCaughey, *Film Effects of Fire Sprinklers On Low Enriched Uranium Storage Systems*, ANS Annual Meeting, 1988.
- W.D. Holmes, *Fire Protection By Sprinklers Where Fissile Materials Are Present*, IAEA-SM-305/62, 1989.
- Rahn H. Ross, *Experimental Results of Water Film Formation On Various Fuel Forms From A Fire Suppression System*, ANS Transaction Journal at New Orleans, 1994.